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Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Sara K. Conrad, Editors

Volume 247 BOREAS TGB-12 Isotropic Carbon Dioxide Data over the NSA

S. Trumbore, E. Sundquist, and G. Winston

National Aeronautics and Space Administration

Goddard Space Flight Center Greenbelt, Maryland 20771

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Susan Trumbore, University of California, Irvine Eric Sundquist and Greg Winston, U.S. Geological Survey, Woods Hole, Massachusetts

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BOREAS TGB-12 Isotopic Carbon Dioxide Data over the NSA

Sue Trumbore, Eric Sundquist, Greg Winston

Summary

The BOREAS TGB-12 team made measurements of soil carbon inventories, carbon concentration in soil gases, and rates of soil respiration at several sites to estimate the rates of carbon accumulation and turnover in each of the major vegetation types. This data set contains information on the carbon isotopic content of carbon dioxide sampled from soils in the NSA-OBS, NSA-YJP, and NSA-OJP sites. Data were collected from 14-Nov-1993 to 10-Oct-1996. The data are stored in tabular ASCII files.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS TGB-12 Isotopic Carbon Dioxide Data over the NSA

1.2 Data Set Introduction

The data collected by the BOReal Ecosystem-Atmosphere Study (BOREAS) Trace Gas Biogeochemistry (TGB)-12 team include CO₂ flux rates and concentrations in the soil atmosphere at selected sites, as well as ¹⁴C measurements of CO₂. Our measurements were designed to cover the winter period.

1.3 Objective/Purpose

The objectives were: To estimate rates of carbon input, turnover, and accumulation in the soils of each of the major vegetation types at the BOREAS study sites. The primary tool was the measure of ¹⁴C content in soils, litter, and soil atmospheres, and the measurement of CO₂ emissions from the soil. To relate our estimates of dynamics of soil carbon to ecosystem models of the carbon cycle, to other measures of C cycling dynamics, to regional models of soil carbon accumulation, and to spatial and temporal models of soil moisture and drainage.

1.4 Summary of Parameters

¹⁴C data are presented in Delta notation (the per mil difference in the ratio of ¹⁴C/¹²C in the sample from that of an absolute standard - 1895 wood). We also express what fraction of the bulk soil was used for radiocarbon measurement - plant macrofossils, chemically extracted clay, etc.).

1.5 Discussion

Winter fluxes of CO₂ are often assumed to be zero in northern environments. Our goal in this series of measurements was to quantify the importance of winter CO₂ emissions to the annual carbon balance at the Northern Study Area (NSA) Young Jack Pine (YJP), Old Jack Pine (OJP), and Old Black Spruce (OBS) tower sites. In addition, radiocarbon measurements of ¹⁴C in CO₂ were used to determine whether winter and summer respiration had different sources. Sites were the same ones used by TGB-01 and TGB-03 for studies of soil respiration during May to October.

The steady-state ¹⁴C content of the atmosphere is determined by the exchange of carbon in CO₂ with that in ocean and biospheric reservoirs. Because of the relatively rapid cycling of carbon between the atmosphere and living biomass, most short-lived plant tissues maintain a ¹⁴C specific activity that equals that of atmospheric CO₂. CO₂ derived from old organic matter that has resided in soils for several hundred years will have lower radiocarbon content than that derived from more recently fixed carbon.

1.6 Related Data Sets

BOREAS TGB-12 Radon222 Activity Data over the NSA

BOREAS TGB-12 Radon222 Flux Data over the NSA

BOREAS TGB-12 Soil Carbon Data over the NSA

BOREAS TGB-12 Soil Carbon and Flux Data of NSA-MSA in Raster Format

BOREAS TGB-01 Soil CH4 and CO2 Profile Data over the NSA

BOREAS TGB-01 NSA SF6 Chamber Flux Data over the NSA

2. Investigator(s)

2.1 Investigator(s) Name and Title

Susan Trumbore Earth System Science University of California Irvine

2.2 Title of Investigation

Input, Accumulation and Turnover of Carbon in Boreal Forest Soils

2.3 Contact Information

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Contact 3:

Greg Winston U.S. Geological Survey Quisett Campus Woods Hole, MA 02543

Contact 4:

Jeffrey A. Newcomer Raytheon ITSS Code 923 NASA GSFC Greenbelt, MD 20771 (301) 286-7858 (301) 286-0239 (fax) Jeffrey.Newcomer@gsfc.nasa.gov

3. Theory of Measurements

Soil fluxes were measured using chamber methods, which involve enclosing the airspace over soil and monitoring the mixing ratio of gases within the chamber over time. For radiocarbon, we needed to trap the CO_2 out of the chamber headspace to collect enough carbon for the ^{14}C measurement. Specifics are given in Winston et al. (1997) and Section 4, below.

Measurements of soil gas concentrations may be combined with estimates of the rate of diffusion in soils to determine the contribution to surface CO₂ emissions derived from various soil depths (see Davidson and Trumbore, 1995, for an example). To do this in BOREAS, we measured CO₂, temperature, and moisture profiles, as well as ²²²Rn for estimating soil diffusivity. Special pits were instrumented with thermistors (for monitoring soil temperature), Time Domain Reflectometry (TDR) probes (for monitoring soil water content), and soil gas probes (1/8" stainless steel tubing, perforated at one end and inserted 50 to 100 cm laterally into the soil pit wall, capped with 1/8" swagelock union fittings sealed with a septum). Further details are given in Winston et al. (1997) and in Section 4, below.

Calculation of a radiocarbon age requires the assumption that the ¹⁴C content of the carbon originally fixed in plant tissues equaled that of the atmospheric CO₂ in 1950 (0.95 times the activity of oxalic acid, or Modern). In fact, the ¹⁴C content of the atmosphere has varied with time because of changes in the production rate of ¹⁴C (cosmic ray flux and magnetic field variations) and because of changes in the distribution of carbon among ocean, biosphere, and atmospheric reservoirs. These variations, deduced from the ¹⁴C content of cellulose of known age taken from the annual growth rings of trees, are generally less than 10% over the past 7,000 years. More recent changes in the ¹⁴C content of atmospheric CO₂ have resulted from dilution by ¹⁴C-free fossil-fuel-derived carbon and by the production of ¹⁴C during atmospheric testing of thermonuclear weapons (bomb ¹⁴C). The latter effect dominates other natural and fossil fuel effects, as the atmospheric burden of ¹⁴C was approximately doubled in the few years preceding the implementation of the Nuclear Test Ban Treaty in 1964. This isotopic spike in the global carbon system provides a means for radiocarbon to be a useful tracer of carbon cycle processes on the scale of decades.

We express ¹⁴C data in the geochemical Delta notation, the deviation in parts per thousand (per mil) from an absolute standard (95 times the activity of NBS oxalic acid measured in 1950). In this notation, zero equals the ¹⁴C content of 1895 wood, positive values indicate the presence of 'bomb' radiocarbon, and negative values indicate the predominance of C fixed from the atmosphere more than several hundred years ago.

For seeds, deciduous leaves, etc., that represent a single year's growth, the ¹⁴C content of recent samples may be used to determine the age of a sample to within a year or two (for samples in the 'bomb' period, <30 years old). The ¹⁴C content of the sample is compared to the ¹⁴C record of atmospheric C in the Northern Hemisphere (see Burcholadze reference, below, as an example). Evergreen needles, that may average several years' growth, will have higher ¹⁴C signatures than deciduous leaves that grew since 1964.

For samples prior to 1960, radiocarbon ages in years may be calculated from the given Delta values as -8033*(ln(Delta*.995/1000 +1)). The conventional radiocarbon age must be converted to a calibrated age using the tree-ring-based calibration curves, which correct for known variations in atmospheric ¹⁴C over time Both ages are usually rounded to the nearest decade or pentade.

One application of radiocarbon to soil science lies in the relatively straightforward 14 C dating of charcoal and plant macrofossils to determine the accumulation rate of C in vertically aggrading soils (like peats, or moss layers). Unlike the closed systems represented by intact macrofossils, such as seeds or pollen, bulk soil organic matter is a heterogeneous reservoir with a variety of turnover times, to which carbon is continuously added (as new plant matter) and lost (as leached organic carbon or CO_2). The radiocarbon content of soil organic matter cannot be interpreted as a 'date,' but represents the average age of a carbon atom in this reservoir.

The breakdown of C into faster- and slower-cycling pools may be determined by combining several approaches; see the articles in Section 17 for more information (this is an evolving research field and no one approach is accepted as valid for all soils).

4. Equipment

4.1 Sensor/Instrument Description

Because all of the equipment used in this project is common to many other projects and no special procedures were used, description detail has been minimized in this section, and the reader is referred to the appropriate publications.

- Davidson and Trumbore, 1995
- Stephens and Sundquist, 1998
- Trumbore and Harden, 1997
- Winston et al., 1997
- Harden et al., 1997

Flux chambers were used to measure CO₂ fluxes and to collect CO₂ for radiocarbon measurements. See Stephens and Sundquist (1998) and Winston et al (1997) for details. Stainless steel (1/8 inch) probes were used to collect soil atmosphere samples from different depths. Samples for CO₂ concentration measurement were removed by syringe; larger volume samples for ¹⁴C determination were collected by attaching pre-evacuated, electropolished, stainless steel cans of 500cc volume.

Lab Equipment - Carlo Erba NA1500 carbon and nitrogen combustion analyzer; vacuum lines for purification of CO₂ from combusted samples and graphite target preparation. The accelerator mass spectrometer (AMS) used for ¹⁴C measurement is described in Southon et al. (1992) and Trumbore (1998).

14CO₂ efflux from soil: Samples for ¹⁴C measurement of total soil respiration are collected from the headspace of a dynamic chamber using molecular sieve 13X traps. First, atmospheric CO₂ trapped during chamber emplacement is removed by circulating headspace air at flow rates of ~500 cm³/min through a soda lime column. Scrubbing continues until the equivalent of two chamber volumes has been passed over the soda lime. The molecular sieve trap then replaces the soda lime scrubber and CO₂ is trapped from circulating chamber air until enough has been collected for isotopic (¹³C and ¹⁴C) measurements. Trapping times vary from about 10 minutes to an hour, depending on the soil CO₂ emission rate. CO₂ is released from the trap at 500 °C, and purified cryogenically. One aliquot of the sample is measured for ¹³C content by stable isotope mass spectrometry. A second aliquot is reduced to graphite for ¹⁴C measurement by AMS. Comparison of ¹³C data for ambient air (sampled at the same site) with the ¹³C content of soil organic matter is used to correct the ¹⁴C data for small amounts of ambient air remaining in the sample.

4.1.1 Collection Environment

Samples were collected mostly in over two winters, though summer measurements were also made for isotopes.

4.1.2 Source/Platform

Ground.

4.1.3 Source/Platform Mission Objectives

None given.

4.1.4 Kev Variables

The key variables are the CO₂ concentration, CO₂ flux and del ¹⁴C of CO₂.

4.1.5 Principles of Operation

None given.

4.1.6 Sensor/Instrument Measurement Geometry

None given.

4.1.7 Manufacturer of Sensor/Instrument

A LI-COR CO₂ analyzer was used to measure CO₂ fluxes in the field. The gas chromatography system described by TGB-01 (Crill) was used to determine CO₂ concentrations in soil air.

4.2 Calibration

4.2.1 Specifications

See Winston et al., 1997.

4.2.1.1 Tolerance

See Winston et al., 1997.

4.2.2 Frequency of Calibration

See Winston et al., 1997.

4.2.3 Other Calibration Information

See Winston et al., 1997.

5. Data Acquisition Methods

¹⁴C. Carbon-14 is measured by accelerator mass spectrometry of graphite targets prepared from CO₂ (see one of several references, including Trumbore, 1995). Samples (of 1-2 mg carbon equivalent) are combusted in vacuum in quartz tubes with cupric oxide wire at 900 °C. The resulting CO₂ is purified cryogenically, then reduced to graphite coating cobalt powder in a sealed Pyrex tube at 500-550 °C with zinc and titanium hydride powder. AMS measurements were made at the Lawrence Livermore National Laboratory Center for Accelerator Mass Spectrometry. One sigma precision is usually +/-8-10 per mil (0.8-1.0 % Modern) and overall accuracy (based on repeated measurements of substandards prepared in the same way as samples) is 1.0-1.5% of Modern (10-15 per mil).

6. Observations

6.1 Data Notes

None given.

6.2 Field Notes

None given.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The North American Datum of 1983 (NAD83) coordinates for the sites are:

Site	Latitude	Longitude	
NSA-OBS	55.88007N	98.48139W	
NSA-YJP	55.89575N	98.28706W	
NSA-OJP	55.92842N	98.62396W	

7.1.2 Spatial Coverage Map

Not applicable

7.1.3 Spatial Resolution

These data are point measurements at the given locations.

7.1.4 Projection

Not applicable.

7.1.5 Grid Description

Not applicable

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The data were collected over the period of 14-Nov-1993 to 10-Oct-1996. Data collection was not continuous; most CO₂ fluxes were measured in winter.

7.2.2 Temporal Coverage Map

None.

7.2.3 Temporal Resolution

None given.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The parameters contained in the data files on the CD-ROM are:

Column Name
----SITE_NAME
SUB_SITE
DATE_OBS
CO2_FLUX
DEL_14C
SITE_COMMENTS
CRTFCN_CODE
REVISION_DATE

7.3.2 Variable Description/Definition

The descriptions of the parameters contained in the data files on the CD-ROM are:

Column Name	Description		
SITE_NAME	The identifier assigned to the site by BOREAS, in the format SSS-TTT-CCCCC, where SSS identifies the portion of the study area: NSA, SSA, REG, TRN, and TTT identifies the cover type for the site, 999 if unknown, and CCCCC is the identifier for site, exactly what it means will vary with site type.		
SUB_SITE	The identifier assigned to the sub-site by BOREAS, in the format GGGGG-IIIII, where GGGGG is the group associated with the sub-site instrument, e.g. HYD06 or STAFF, and IIIII is the identifier for sub-site, often this will refer to an instrument.		
DATE_OBS	The date on which the data were collected.		
CO2_FLUX	Carbon Dioxide flux.		
DEL_14C	The del 14C is a relative difference between the sample and the 95% oxalic acid 1 standard, relative to the 95% oxalic acid 1 standard.		
SITE_COMMENTS	Descriptive information to clarify or enhance the site information.		
CRTFCN_CODE	The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified		

by Group), PRE (Preliminary), and CPI-??? (CPI but

questionable).

REVISION_DATE The most recent date when the information in the

referenced data base table record was revised.

7.3.3 Unit of Measurement

The measurement units for the parameters contained in the data files on the CD-ROM are:

Column Name	Units		
SITE_NAME	[none]		
SUB_SITE	[none]		
DATE_OBS	[DD-MON-YY]		
CO2_FLUX	[micromoles][meter^-2][second^-1]		
DEL_14C	[per mil]		
SITE_COMMENTS	[none]		
CRTFCN_CODE	[none]		
REVISION_DATE	[DD-MON-YY]		

7.3.4 Data Source

The sources of the parameter values contained in the data files on the CD-ROM are:

Column Name	Data Source
SITE_NAME	Not applicable
SUB_SITE	Not applicable
DATE_OBS	Investigator
CO2_FLUX	LI-COR
DEL_14C	Accelerator mass spectrometry
SITE_COMMENTS	Investigator
CRTFCN_CODE	Not applicable
REVISION_DATE	Not applicable

7.3.5 Data Range

The following table gives information about the parameter values found in the data files on the CD-ROM.

	Minimum Data	Maximum Data	Missng Data	Unrel Data	Below Detect	Data Not
Column Name	Value	Value	Value	Value	Limit	Cllctd
SITE_NAME	NSA-9BS-T12GR	NSA-YJP-FLXTR	None	None	None	None
SUB_SITE	TGB12-FLX01	TGB12-FLXCB	None	None	None	None
DATE_OBS	14-NOV-93	10-OCT-96	None	None	None	None
CO2_FLUX	0	1.41666667	None	None	None	Blank
DEL_14C	-71.16	188.81	-999	None	None	Blank
SITE_COMMENTS	N/A	N/A	None	None	None	None
CRTFCN_CODE	CPI	CPI	None	None	None	None
REVISION_DATE	26-AUG-96	03-SEP-97	None	None	None	None

Minimum Data Value -- The minimum value found in the column.

Maximum Data Value -- The maximum value found in the column.

Missng Data Value -- The value that indicates missing data. This is used to indicate that an attempt was made to determine the

parameter value, but the attempt was unsuccessful.

Unrel Data Value -- The value that indicates unreliable data. This is used to indicate an attempt was made to determine the parameter value, but the value was deemed to be unreliable by the analysis personnel. Below Detect Limit -- The value that indicates parameter values below the instruments detection limits. This is used to indicate that an attempt was made to determine the parameter value, but the analysis personnel determined that the parameter value was below the detection limit of the instrumentation. Data Not Cllctd -- This value indicates that no attempt was made to determine the parameter value. This usually indicates that BORIS combined several similar but not identical data sets into the same data base table but this particular science team did not measure that parameter. Blank -- Indicates that blank spaces are used to denote that type of value. N/A -- Indicates that the value is not applicable to the respective column. None -- Indicates that no values of that sort were found in the column.

7.4 Sample Data Record

The following are wrapped versions of data record from a sample data file on the CD-ROM.

```
SITE_NAME,SUB_SITE,DATE_OBS,CO2_FLUX,DEL_14C,SITE_COMMENTS,CRTFCN_CODE,REVISION_DATE
'NSA-YJP-FLXTR','TGB12-FLX01',14-NOV-93,.07407407,,'open snow','CPI',26-AUG-96
'NSA-YJP-FLXTR','TGB12-FLX01',14-NOV-93,.09953704,,'open snow','CPI',26-AUG-96
'NSA-YJP-FLXTR','TGB12-FLX01',14-NOV-93,.10648148,,'over twig - rabbit track','CPI',26-AUG-96
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data tracked by the BOREAS Information System (BORIS) was the CO₂ flux measured for a given site on a given day.

8.2 Data Format(s)

The Compact Disk-Read-Only Memory (CD-ROM) files contain American Standard Code for Information Interchange (ASCII) numerical and character fields of varying length separated by commas. The character fields are enclosed with single apostrophe marks. There are no spaces between the fields.

Each data file on the CD-ROM has four header lines of Hyper-Text Markup Language (HTML) code at the top. When viewed with a Web browser, this code displays header information (data set title, location, date, acknowledgments, etc.) and a series of HTML links to associated data files and related data sets. Line 5 of each data file is a list of the column names, and line 6 and following lines contain the actual data.

9. Data Manipulations

9.1 Formulae

None given.

9.1.1 Derivation Techniques and Algorithms

None.

9.2 Data Processing Sequence

None given.

9.2.1 Processing Steps

None given.

9.2.2 Processing Changes

None given.

9.3 Calculations

None given.

9.3.1 Special Corrections/Adjustments

None given.

9.3.2 Calculated Variables

None.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

We have assumed -25 per mil ¹³C in correcting ¹⁴C data for fractionation (error of 2 per mil in this term leads to a 4 per mil error in Del ¹⁴C -- as long as vegetation is predominantly C3 photosynthetic pathway, this is not a large contributing error in ¹⁴C analyses).

10.2 Quality Assessment

10.2.1 Data Validation by Source

None given.

10.2.2 Confidence Level/Accuracy Judgment

None given.

10.2.3 Measurement Error for Parameters

None given.

10.2.4 Additional Quality Assessments

None given.

10.2.5 Data Verification by Data Center

Data were examined for general consistency and clarity.

11. Notes

11.1 Limitations of the Data

None given.

11.2 Known Problems with the Data

None given.

11.3 Usage Guidance

None given.

11.4 Other Relevant Information

None.

12. Application of the Data Set

One application of radiocarbon to soil science lies in the relatively straightforward 14 C dating of charcoal and plant macrofossils to determine the accumulation rate of C in vertically aggrading soils (like peats, or moss layers). Unlike the closed systems represented by intact macrofossils, such as seeds or pollen, bulk soil organic matter is a heterogeneous reservoir with a variety of turnover times, to which carbon is continuously added (as new plant matter) and lost (as leached organic carbon or CO_2). The radiocarbon content of soil organic matter cannot be interpreted as a 'date,' but represents the average age of a carbon atom in this reservoir. As such, dating various layers in the soil can give modelers information about the carbon accumulation and release rates over time and potentially relate this to climate changes and effects.

13. Future Modifications and Plans

The data will be published as a USGS open file report in the future.

14. Software

14.1 Software Description

None given.

14.2 Software Access

None given.

15. Data Access

The TGB-12 isotopic carbon dioxide data are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services Oak Ridge National Laboratory P.O. Box 2008 MS-6407 Oak Ridge, TN 37831-6407

Phone: (423) 241-3952 Fax: (423) 574-4665

E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

None.

16.2 Film Products

None.

16.3 Other Products

These data are available on the BOREAS CD-ROM series.

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

None given.

17.2 Journal Articles and Study Reports

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17.3 Archive/DBMS Usage Documentation None.

18. Glossary of Terms

None given.

19. List of Acronyms

AMS - Accelerator Mass Spectrometer

ASCII - American Standard Code for Information Interchange

BOREAS - BOReal Ecosystem-Atmosphere Study

BORIS - BOREAS Information System

CD-ROM - Compact Disk-Read-Only Memory

DAAC - Distributed Active Archive Center

EOS - Earth Observing System

EOSDIS - EOS Data and Information System
GIS - Geographic Information System
GSFC - Goddard Space Flight Center
HTML - Hyper-Text Markup Language

MSA - Modeling Sub-Area

NAD83 - North American Datum of 1983

NASA - National Aeronautics and Space Administration

NSA - Northern Study Area

OA - Old Aspen

OBS - Old Black Spruce
OJP - Old Jack Pine

ORNL - Oak Ridge National Laboratory
PANP - Prince Albert National Park

SSA - Southern Study Area

TDR - Time Domain Reflectometry

TE - Terrestrial Ecology

TGB - Trace Gas Biogeochemistry
URL - Uniform Resource Locator

USGS - United States Geological Survey

YJP - Young Jack Pine

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The BOREAS TGB-12 team made measurements of soil carbon inventories, carbon concentration in soil gases, and rates of soil respiration at several sites to estimate the rates of carbon accumulation and turnover in each of the major vegetation types. This data set contains information on the carbon isotopic content of carbon dioxide sampled from soils in the NSA-OBS, NSA-YJP, and NSA-OJP sites. Data were collected from 14-Nov-1993 to 10-Oct-1996. The data are stored in tabular ASCII files.

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